PFN DESIGN INTERFACE WITH E-BEAM SUSTAINED GAS DISCHARGE

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ABSTRACT

The non-linear time varying conductivity characteristics of electron beam sustained gas discharges require special consideration in the design interface with the pulse forming network in line type modulators. Equations and tables are used to analyze effects of varying E/N, a non-uniform electron beam, and the interaction with the PFN. Experimental data is compared to calculations and found to be in reasonable agreement.

Introduction

The fundamental equation of conduction in a gas without a magnetic field is given by (1)

$$j = en_e Vd = \sigma E \quad (\text{Amps/cm}^2) \tag{1}$$

or

$$\sigma = \frac{en_e Vd}{E} \quad (\text{MHO - cm}) \tag{2}$$

Thus to find the conductivity (σ), the electron number density (n_e), the drift velocity (Vd) and the electric field (E) must be evaluated.

The electron number density is found by solving equation (3)

$$\frac{dn_e}{dt} = SNj_{eb} - Rn_e^2 - ANn_e + INn_e - Dif \tag{3}$$

The right hand terms are respectively the source term which is the rate at which electrons are generated by the E-beam ionizing the gas, the recombination term is the rate electrons recombine with ionized molecules, the attachment term is the rate electrons attach to neutral molecules, the ionization term is the rate electrons are generated by the electric field and the diffusion term is the rate electrons diffuse from the region. R, A, I and the drift velocity Vd are given in figures 1-4. (Ref 1)

In pulse cases the diffusion term can be neglected also the ionization and attachment terms are usually negligible.

The source coefficient S is given by equation (4).

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14. ABSTRACT

The non-linear time varying conductivity characteristics of electron beam sustained gas discharges require special consideration in the design interface with the pulse forming network in line type modulaters. Equations and tables are used to analyze effects of varying E/N, a non-uniform electron beam, and the interaction with the PFN. Experimental data is compared to calculations and found to be in reasonable agreement.

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$$S = \frac{1}{e} \sum_{i=1}^{K} \frac{P_i \frac{\partial E}{\partial m}\Big|_i}{E_i} \qquad (4)$$

where $\frac{\partial E}{\partial M}$ is figure 5 (ref 2)

P_i = Mass density g/cm^3

E_i = effective ionization energy of the ith specie in eV (N_2, $CO_2 \approx$ 34 eV, He $\approx$ 50 eV)

From equation (4) the values of S for 871, 541 and 321 mixes are:

$$S_{871} = 8.66$$
$$S_{541} = 8.92$$
$$S_{321} = 9.55$$

The drift velocity is a function of E/N and depends slightly on mix as shown in figure 4.

From the foregoing the conductivity may now be evaluated as a function of time, etc and geometrical dimensions are thereby used to predict the electrical interaction with the PFN.

Method of Analysis

To obtain a feel for the nature of conductivity behavior first consider the simple case of a small volume of gas with a constant electric field which is then step illuminated with an uniform electron beam. Since the E-field is constant, E/N is constant and the coefficients of equation (3) and Vd are constant, neglecting the A and I terms as small compared to R, equation (3) gives

$$n_e \cong \sqrt{\frac{SNjeb}{R}} \tanh(\sqrt{SNRjeb}\ t) \qquad (5)$$

so the conductivity is

$$\sigma \cong \frac{eVd}{E} \sqrt{\frac{SNjeb}{R}} \tanh(\sqrt{SNRjeb}\ t) \qquad (6)$$

The conductivity increases from zero to a steady state value in an expotential manner. For an atmospheric 3:2:1 mix at 5 Kv/cm and jeb = .01 A/cm^2 the time constant of the tanh function is about 1.25 microseconds (figure 6).

Now consider what happens to the conductivity under the same conditions except it is in steady state conduction and the E-beam is step switched off. The initial steady state electron number density and corresponding conductivity is given by

$$n_e(ss) \approx \sqrt{\frac{SNjeb}{R}}, \quad \sigma_{(ss)} \cong \frac{eVd}{E} \sqrt{\frac{SNjeb}{R}} \qquad (7)$$

Solving (3) with jeb = 0 and retaining the A and I terms to avoid a

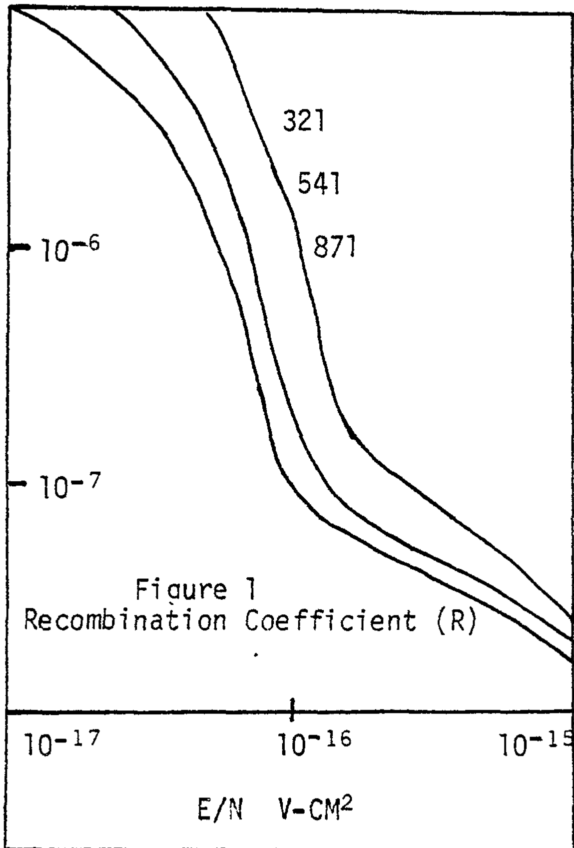

Figure 1
Recombination Coefficient (R)

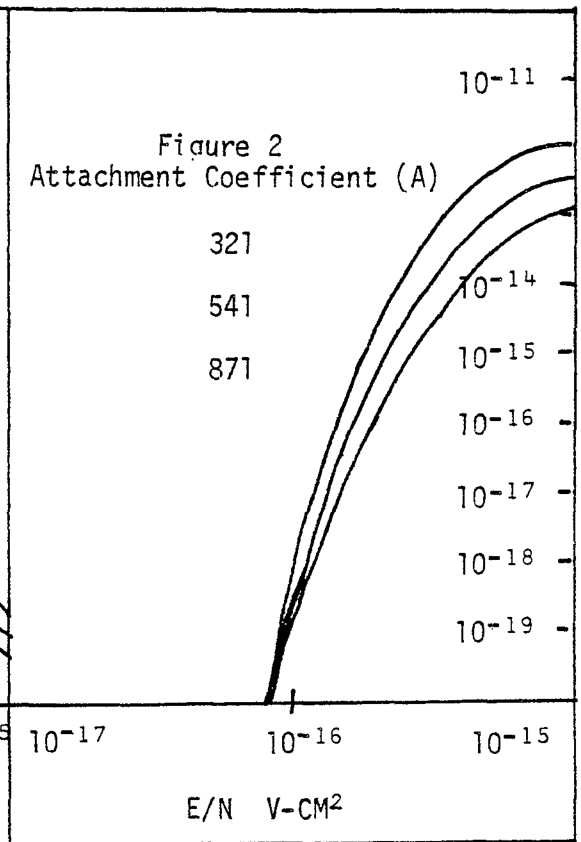

Figure 2
Attachment Coefficient (A)

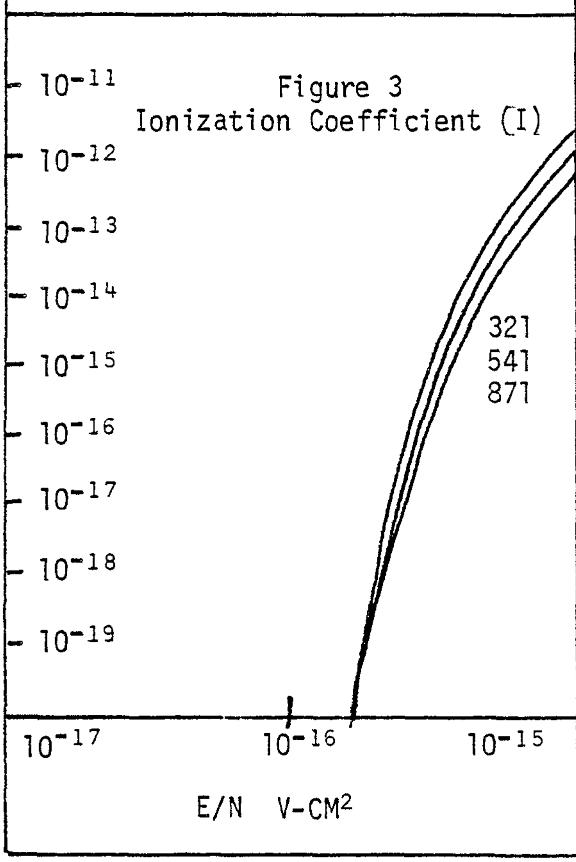

Figure 3
Ionization Coefficient (I)

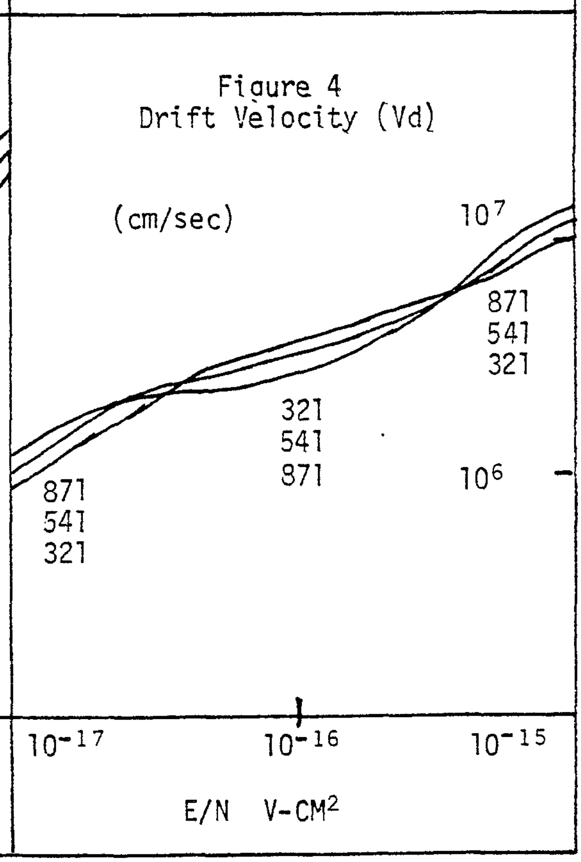

Figure 4
Drift Velocity (Vd)

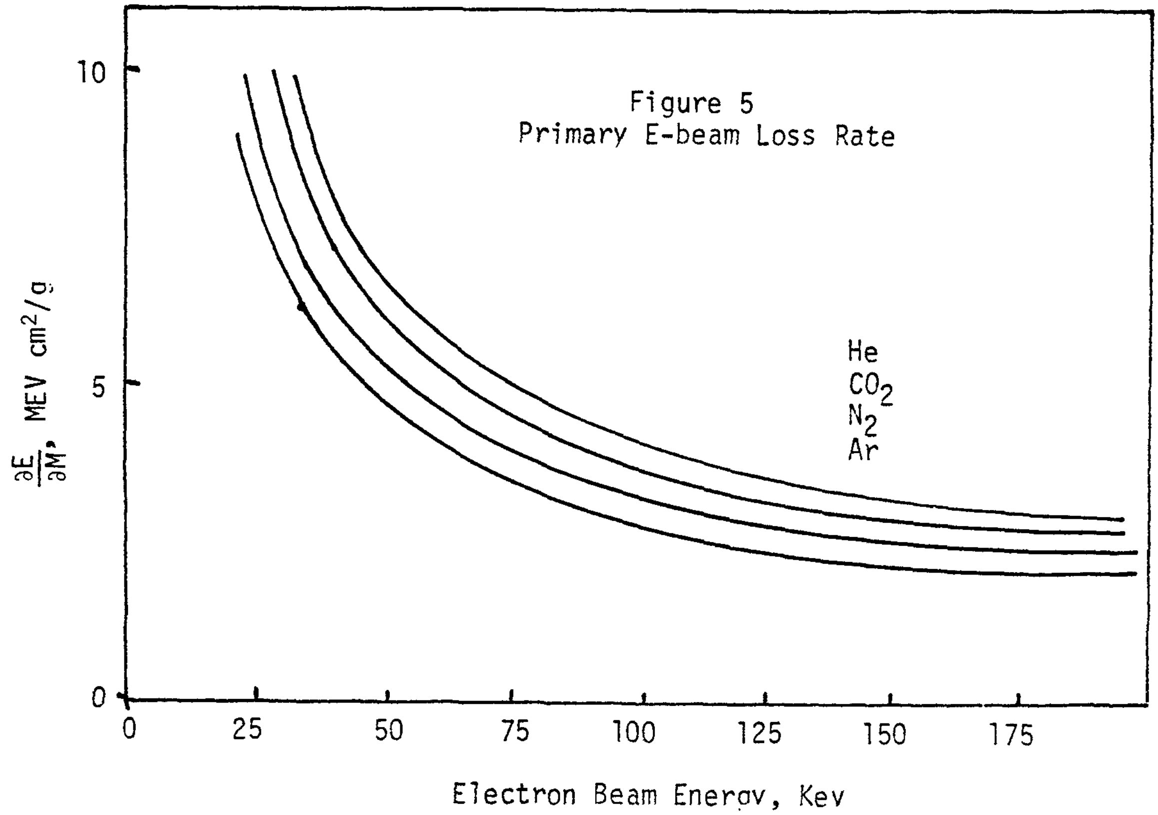
Figure 5
Primary E-beam Loss Rate
He
CO_2
N_2
Ar
10
5
0
$\frac{\partial E}{\partial M}$, MEV cm^2/g
0
25
50
75
100
125
150
175
Electron Beam Energy, Kev

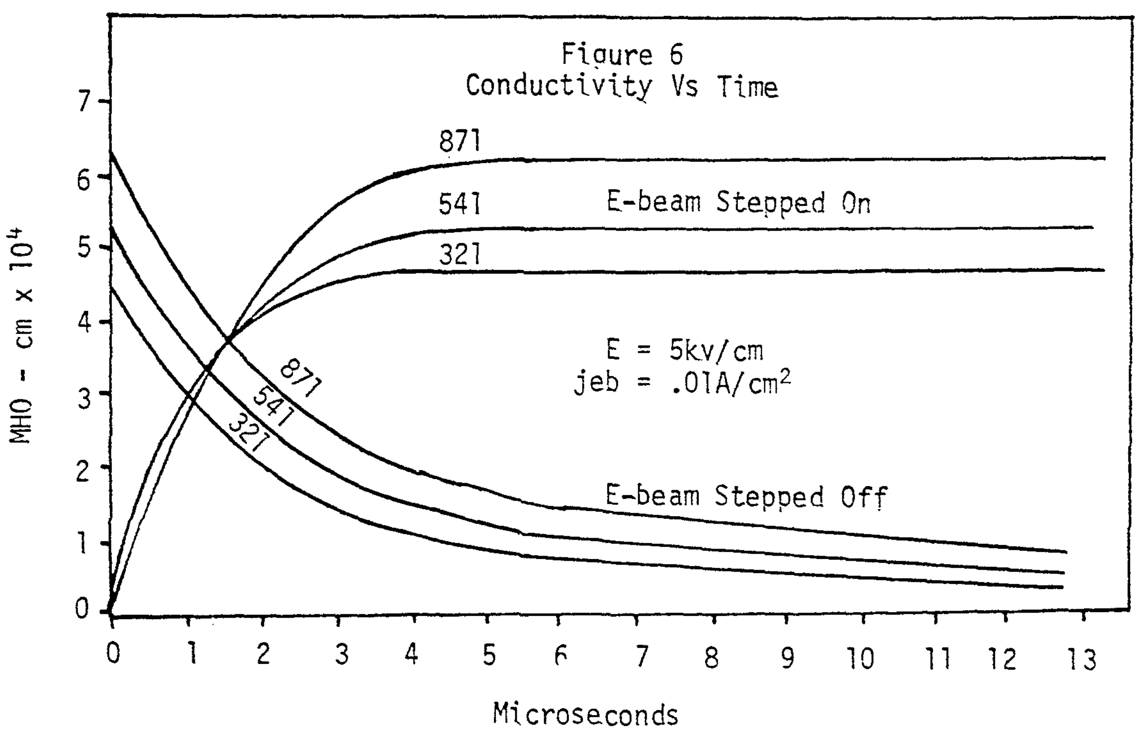
Figure 6
Conductivity Vs Time
871
541
321
E-beam Stepped On
E = 5kv/cm
jeb = .01A/cm^2
871
541
321
E-beam Stepped Off
MHO - cm x 10^4
0
1
2
3
4
5
6
7
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Microseconds

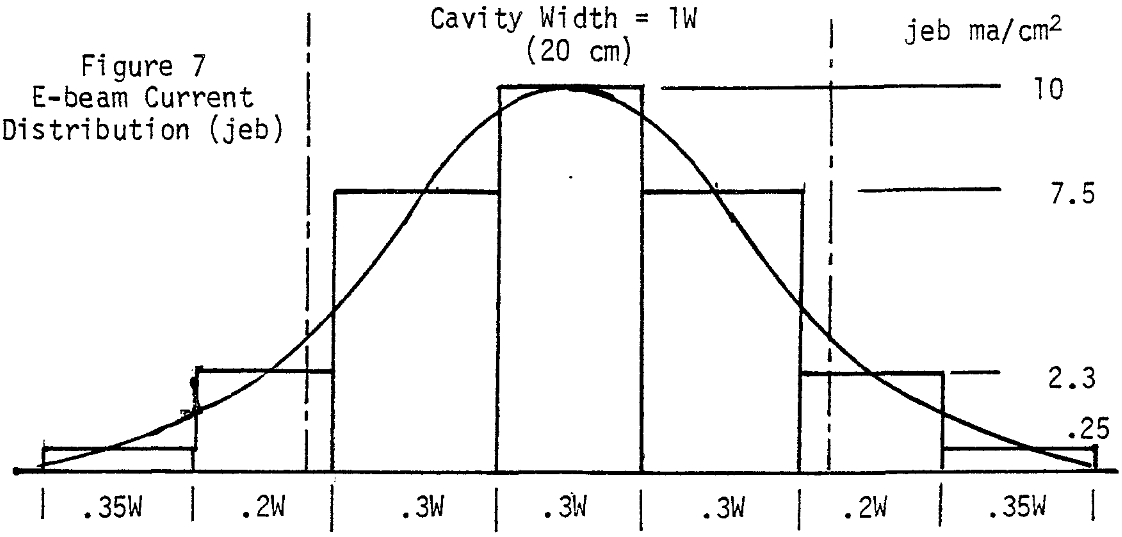

Figure 7
E-beam Current
Distribution (jeb)

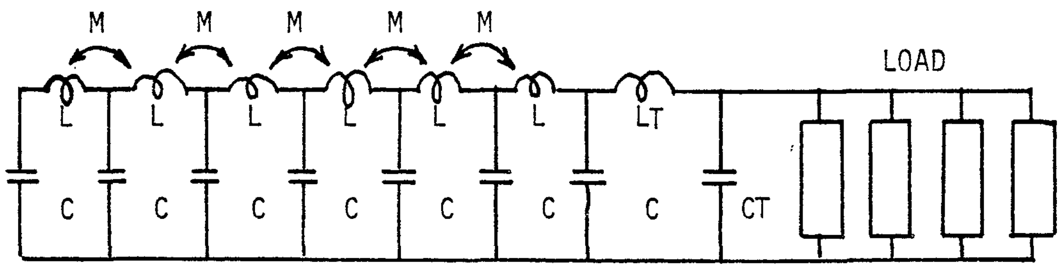

Figure 8 PFN - Load Circuit Model

L = 4.86μh, C = .248μfd, M = .65μh
LT = 21μh, CT = 1000pf

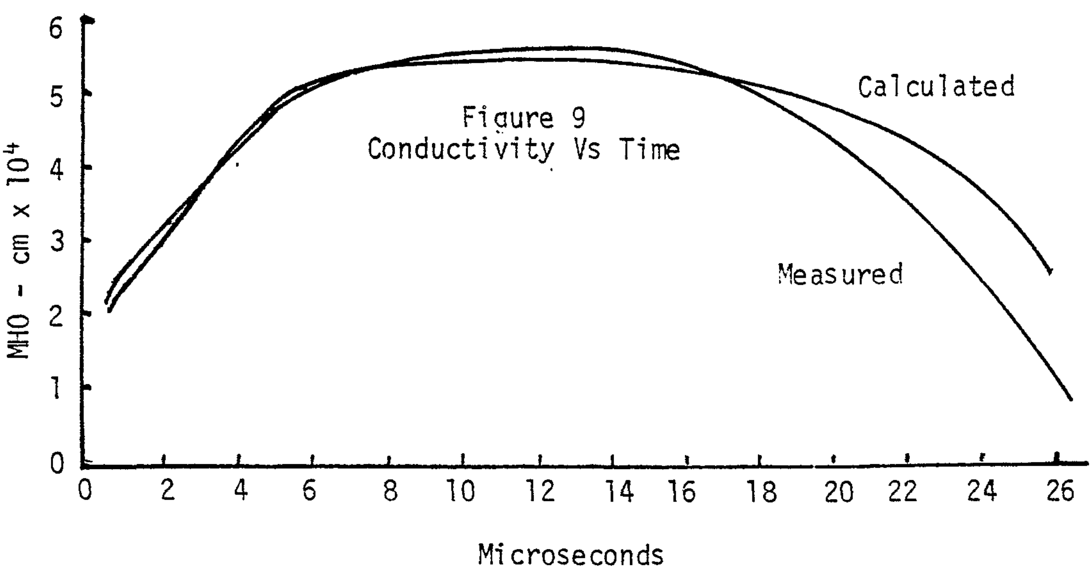

Figure 9
Conductivity Vs Time

discontinuity at t = 0, the conductivity becomes

$$\sigma = \frac{eVd\sqrt{SNjeb}\,N(A-I)}{E((N(A-I)\sqrt{R} + R\sqrt{SNjeb})\varepsilon^{N(A-I)t} - R\sqrt{SNjeb})} \tag{8}$$

The exponential decay time constant is about 2.75 microseconds for a 3:2:1 mix compared to 1.25 microseconds when the E-beam was switched on. These times are about the same for the other mixes. (Figure 6)

Extending the analysis to a typical real gas load must include consideration of the changing E/N during the pulse, the effect of a non-uniform E-beam current density and the interaction with the PFN impedance. This is accomplished by tabulating or fitting equations to the E/N dependent parameters, approximating the E-beam current distribution and solving the PFN load circuit equations in sufficiently small time steps via a computer program.

It is necessary to consider the E-beam current density distribution because not only the steady state conductivity but also the time constant of the conductivity is affected. To account for this, the jeb density variation may be fitted to a curve or approximated by a multistep distribution as in figure 7. Note that the density typically extends beyond the boundary of the load cavity. Each segment is treated as a parallel impedance connected to the PFN as in figure 7.

A SCEPTRE solution of figure 7 for a 3:2:1 mix in a 10 x 20 x 200 centimeter cavity at 60 Kv (20 microseconds) was run and is compared to the experimented test data in figure 8. Note that the conductivity (averaged over the whole load) tends to slowly increase over the front of the pulse. This is attributed to the fact that the lower jeb regions take longer to build up to steady state conductivity and thus contribute to the overall conductivity later in the pulse. Note also that the inductance of the first section of the PFN is 4.3 times the middle section inductance whereas for a resistive load it would be about 1.15 times. This higher value is required with the gas load to prevent voltage overshoot also it need not be lumped in the network but may be included as the leakage inductance of the pulse transformer thus allowing for a much less demanding transformer design compared to a resistive load. The decrease of the experimental conductivity more rapidly than the model in figure 9 is attributed to the presence of a small amount of O_2 which has a very high attachment rate.

References

1. Data on R, A, I and Vd provided from internal memos of Maj J. D. Hines, AFWL.

2. CO_2 Electric Discharge Laser Kinetics Handbook, AFWL-TR-74-216, D. H. Douglas-Hamilton, R. S. Lowder.